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Crack Detection and Geometry Measurements using Digital Image Processing

Dhia A. Alazawi, Zaid S. Hammoudi, Mohanad N. Mohammed *

Department of Mechanical Engineering, College of Engineering, University of Diyala, 32001 Diyala, Iraq

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ABSTRACT

Digital image processing (DIP), is the use of a digital computer to process digital images through an algorithm. In this work DIP used to perform crack/defect Detection and geometry measurements in terms of angle, length, and width by building a MATLAB code. In this research, the test of tensile were applied on two flat samples, the two flat samples are painted in a speckle pattern on the tested surface to use DIP features. The DIP gives a low-cost optical, and an appropriate technique to detect crack/defect as well as geometry measurements with the load increment in terms of angle, length and width without any contact with the tested surfaces. The tests directed for both of flat Aluminum alloy and Copper alloy specimens. In order to guarantee the efficiency of the planned DIP systems, the comparison is considered between the test results of this technique with the measurements gained by actual physical by using calibrated digital vernier calliper (IP 54) to measure the length of the crack with 0-300 mm range and 0.01 mm resolution. The DIP obtained percentage of accuracy varies from (97) % to (99) % by comparison with the measurements gained by actual physical way.

1. Introduction

The digital image processing (DIP) is optical techniques appropriate to detect crack/defect location as well as geometry measurements in terms of angle, length and width. DIP techniques have widely been used in experimental researches due to their simplicity and low-cost applicability and simple installation of equipment [1-4]. The DIP program has been used to perform crack/defect location detection as well as geometry in terms of angle, length, and width measurements. A program has been developed using MATLAB programming language to check the applicability and effectiveness of this method [5]. In recent years, the detection of cracks/defects has been the main research area in terms of the improvement of experimental techniques [6]. Cracks/defects are considered as one of the essential aspects of mechanical failure studies. Crack/defects detection and geometry measurements are involved in many mechanical applications. Recently, most of the complex calculations and/or investigations need crack/defects detection and geometry measurements at any point inside the region of interest (ROI) to study the specification and behaviour of materials and structural components to make the best material selection in design. For this reason, designers and researchers are interested in having the full-

*Corresponding author.
E-mail address: mohanadnazhan@gmail.com
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field surface investigation for the specimen. DIP techniques and that aspect discuss the way that the DIP detects crack, notch, and/or groove. The recognition of the cracks is not by itself an signal or guess of the end of the structure working life. Though, the surveys of the cracks are important for the assessment of structure working life. Precise demonstrating of the crack is a crucial matter for material behaviour [7]. As it is well known, there are numerous constructions under to fatigue loadings collapse, because there are no initial surface crack and/or defects findings. The important reason for the collapse is the multi-initiations of short cracks on constructions surface [8, 9]. Manual constructions surface check has many difficulties. For example, the micro-cracks, the time cost, and it requirements an expert's acquaintance. For that reason, this can be changed and directed using an automatic way that explains why the experimental necessity comes with DIP. This paper uses a MATLAB program that auto recognizes the defect/cracks, and this has been executed by applying one of the image processing algorithms. In this research, survey papers and studies related to the crack, detection has investigated. Crack detection is the process of detecting the crack in the structures using any of the processing techniques. The crack detection can be made in two ways, destructive testing and non-destructive testing. By incorporating the visual examination and surveying tools, surface condition deficiencies are evaluated [10]. Yiyang et al. [11] have proposed a crack detection algorithm based on digital image processing technology. By preprocessing, image segmentation and feature extraction [11], they have obtained the information about the crack image. Threshold method of segmentation was used after the smoothening of the accepted input image. To judge their image, they have calculated the area and perimeter of the roundness index. Then by the comparison, they have been evaluated the presence of the crack in the image.

The major advantage of the image-based analysis of the crack detection is that by using the image processing technique it provides accurate result compared to the conventional manual methods [12].

Jandejsek, D. Vavric [13] work and figure out the application of DIC to determine the actual crack position had succeed throughout the paper application. This knowledge leads them to calculate the full-field strain and stress. Moreover, it allows them to measure the geometry of the actual length of the crack.

J. Lyngbye and R. Brincker [14] they found on the test of their proposed DIC technique it is concluded in that test, there is no dependence between the measured crack length and loading of the test specimen. The importance of their conclusion items that uncertainty of the DIC system is of the same magnitude or less than the one uncertainty by using a traditional manual technique.

Y. Hos, M. Vormwald AND J.L.F. Freire C4. [15] They have studied the fatigue crack growth in other meaning propagation under different loading cases – especially cases with non-proportional loading. They have concentrated on the deformation fields in the around the crack tip. The check results were very positive. In their work, the important information coming from both of the measurements and simulations that analyzed to improve and understand the non-proportional mixed-mode fatigue crack growth.

P.L. Reu, B.R. Rogillio and G.W. Wellman [16], they current a proposed technique for measurement crack lengths through surface strain measurements. They used the DIC method to find the crack with the help of X-Ray to expose the exact crack location as well. Besides, they did that by tracking an identified surface strain, the crack length has computed for individually load step. The surface strain related to the crack tip has performed through x-ray examination to be 10% for this material and experiment configuration. The stated tests had directed on two stainless steels, 304L and 17-4 PH.

Mohsin Abbas Aswad [17] an experiment had been applied on Alpha-Alumina, he found out that the crack path was clear. Still, the crack tip is hard to distinguish by using an optical microscope. He did find that minimum tested surface crack opening by DIC around 0.05μm with minimum load 53.1N. The DIC used to compute the surface crack was opening shifting at micro-scales.

Sriram.H1, Yogesh W2, Dr.M. Ramjiand3, Dr.Viswanath C4. [18] they worked to get the values of the Stress Intensity Factor (SIF) that obtained from experimentally, analytically and numerically were found out these values are within error limits the J-Integral values that are obtained from analytical and numerical methods. Besides, they showed the relation between the variables J-Integral and the Crack Opening Displacement, and they found out, it depends upon the method of estimation of the CTOD, specimen geometry, and the aspect ratio.

Zaid S. Hammoudi [22] he used FEM principles as 2D formula to estimate the stresses by using ANSYS program, and by the mean of this way the work can be developed to perform the strain calculations.

2. Manual crack length detection

For measuring the crack length, various standard experiments need to be performed whenever crack length has to be measured. It is common in many types of research and tests that the crack length could be measured using various methods for crack length detection; visual, potential drop, compliance, clip gauge, etc.

Each method has both advantages and disadvantages, but here the method that had used its calibrated digital Vernier calliper (IP 54) to measure physically the length of the crack with 0-300 mm range and 0.01 mm resolution.

The visual method is considered as the most general way among many methods for 2-D measuring, and it does not require prior knowledge of the tested specimen or loading. In practice, the crack length measuring is often performed with a microscope, and a length scale is drawn or etched on the surface of the specimen. To eliminate these disadvantages, the program based on digital image processing (DIP) has developed to carry out the crack geometry measuring.

To obtain the most accurate results for the cracking in the ductile materials, it is essential to detect crack/defect position as well as geometry measurements in terms of angle, length and width. Moreover, the finding of the crack is significant in addition to the shape and location of the crack throughout the crack growth. DIP can be used to get the actual position of the crack tip and then compute the crack geometry, see Fig 1.

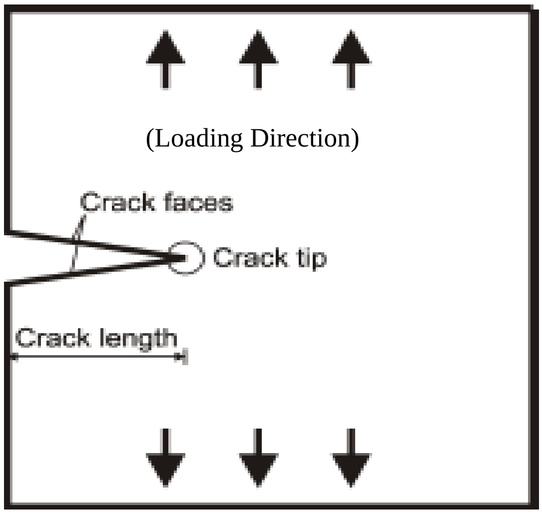


Figure 1. The crack opening under tensile load [19]

In the DIP technique, the crack length is measured in pixels. The developed program has been used to carry out this work and transform pixels to actual physical length units. The cm-scale shown in Fig 2 has put on the specimen surface just before the experiment started. When a crack length measuring is performed, the MATLAB code routine will detect the resolution in pixels per mm, and the actual physical position of the left edge of the image. Furthermore, the MATLAB code routine searches the whole ROI of the specimen surface.

The surface lengths of observed cracks can be obtained directly from the DIP data using image segmentation of the tested specimen. The width and the angle of the cracks may also be derived.

3. Crack length and geometry estimation

DIP is a new technique that has used in laboratories and industry in recent years. This specific tendency is supposed to be continuous, and that means DIP might be more common in the future.

In the DIP technique, the crack length is measured in pixels. A MATLAB code routine program has been written to give the crack geometry in mm, by the transformation from pixels to mm length unit.digital vernier calliper (IP 54) as shown in Fig 2 is used on to measure actual physical crack measurements, before each load step a picture is taken to check the validity of this technique.

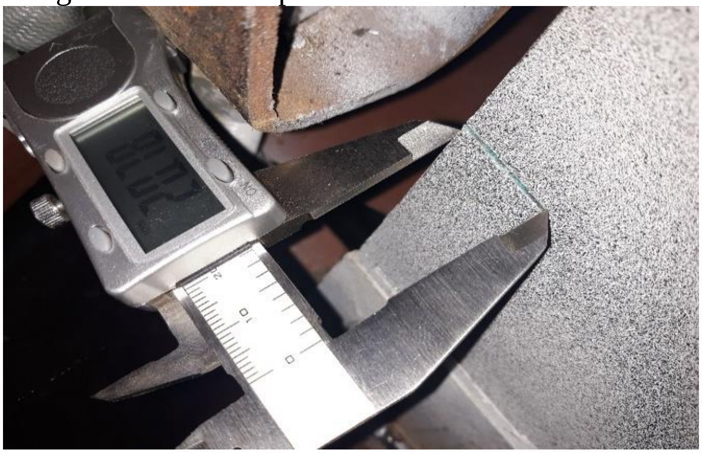
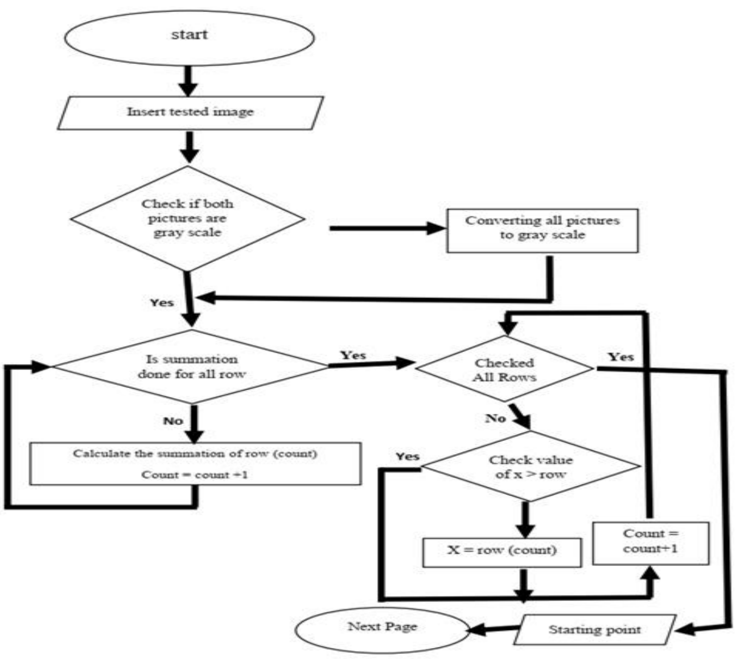


Figure 2. Actual physical crack measurements

4. DIP program approach

The programming aspect that is considered an essential part of this research is related to DIP that is used to compute the crack/defect position and geometry in terms of length, width, and angle. The developed program had been written as per the flow chart is shown in Fig 3. In this work, the program based on DIP has been developed to measure the crack lengths in metal plates. To measure the crack geometry with DIP, it is necessary to start with notching and measuring the first length of the notch that appeared in first captured images. When the crack length is increased by increasing the load applied, the program validity can be checked and re-viewed continuously throughout the image series processing.



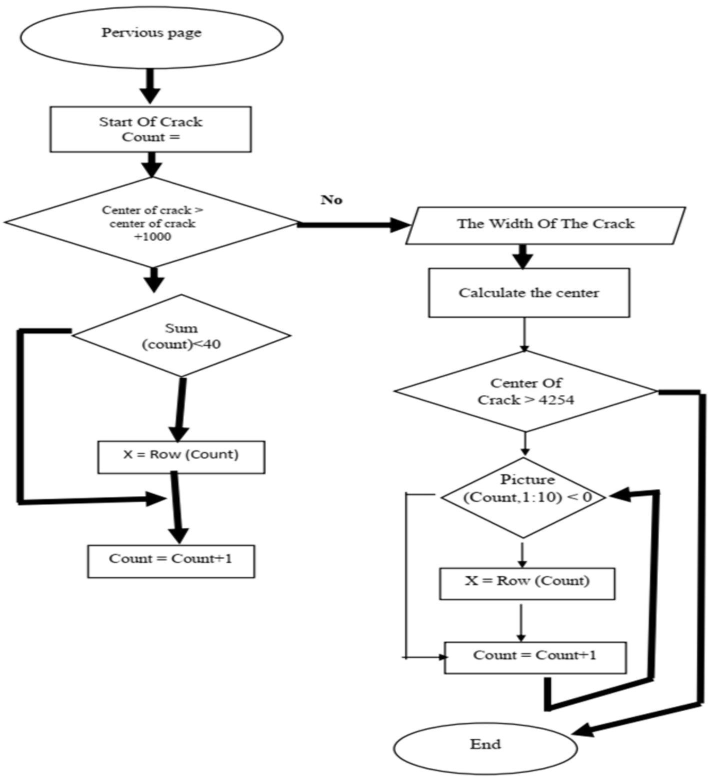


Figure 3. Flowchart of the DIP program that used to measure the crack

5. Crack geometry using DIP.

In this work, the program based on DIP has been developed to measure the crack lengths in metal plates. To measure the crack geometry with DIP, it is necessary to start with notching and measuring the first length of the notch that appeared in first captured images. When the crack length is increased by increasing the load applied, the program validity can be checked and reviewed continuously throughout the image series processing.

The crack summation, see Fig 4, has an expression for the total number of pixels within the crack geometry, when the pixels are unorganized in terms of pixels in the crack tip detected by the camera.

$$\textbf{Crack Length} = \sum_{i=1}^{n}(\textbf{\textit{the pixels with lowest grey values}})$$

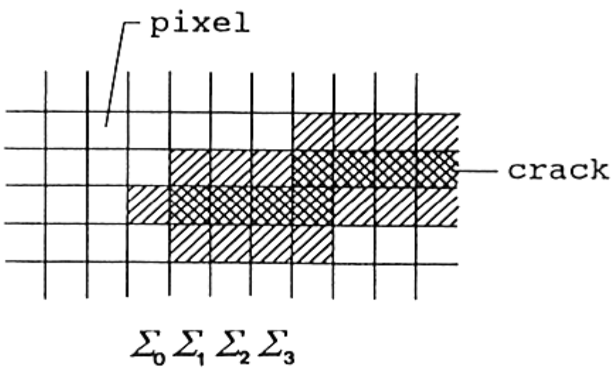


Figure 4. Summation of pixels across the crack

When a crack length measuring is When a crack length measuring is performed, the MATLAB code routine detects the physical position of the left edge of the crack/defect edge just by scanning vertically to know the lowest grey value that represents the crack position. The

MATLAB code routine will search more in the neighborhood of the crack to make sure enough that the program in the crack indeed. The MATLAB code routine examines the completely wide plate, and when it is found, the pixel grey in the vertical columns is scanned, subsequently.

6. Crack / defect experimental in respect to DIP

The considered tests contain the gradual rise of the tensile load by taking the continuous images with that load rising to check the crack geometry continuously. The notch is designed to be as a 30 mm length and 1.2 mm width in Copper specimen and 20mm, 0.8 mm length and width respectively as a notch in Aluminum specimen. The specimen is signified in a plate of Aluminum and Copper alloy which used in the test-loading rig. It was made exactly for this test to work as a examination rig which used to performed loading on to the specimen as a tension test. The 24.2-megapixel Digital Single-Lens Reflex (DSLR) camera, and a Tamron lens with a resolution exceeded the level of 40 lpmm has been used as optics. Fig 5 shows the results gained from the examined pictures.

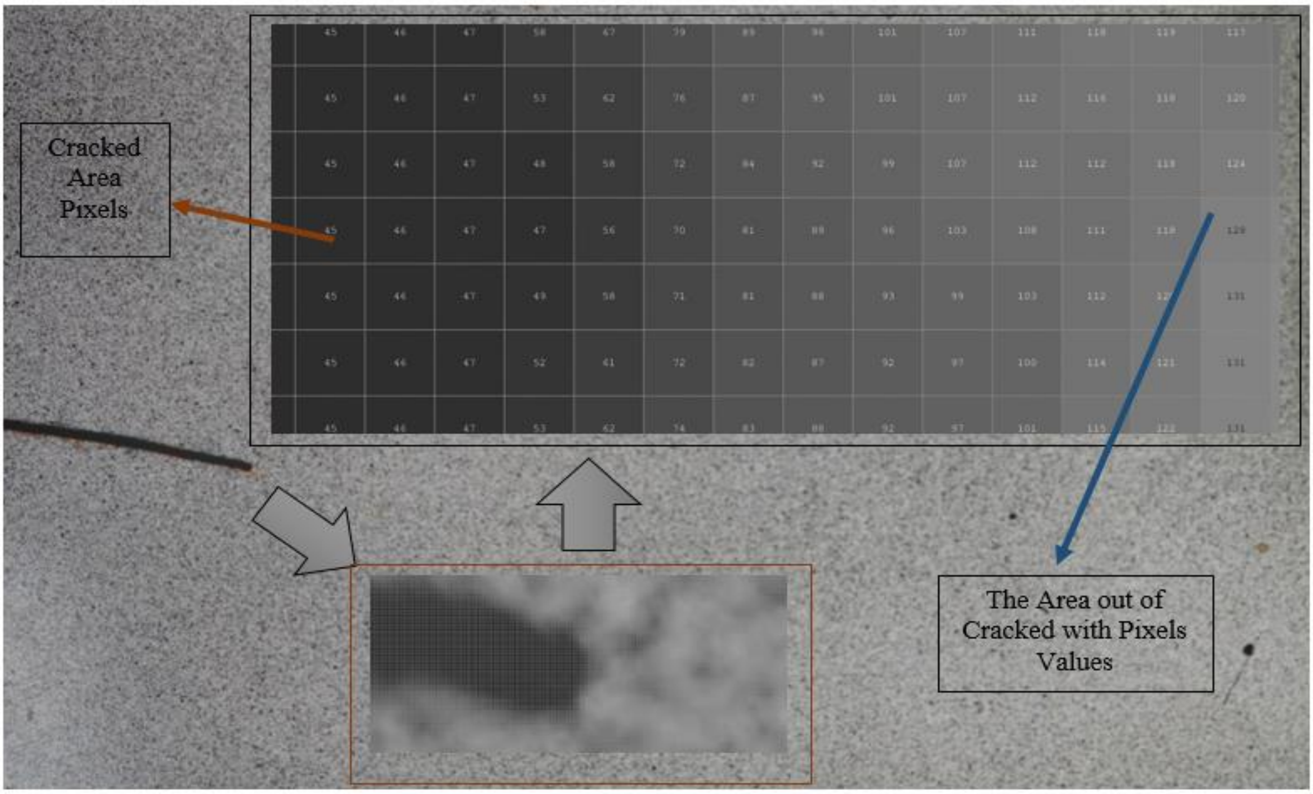


Figure 5. Crack path in pixels

7. Experimental test rig

The primary and general principles to have the displacements of the experienced plates is through these steps, which can be as brief as follows:

i. The camera used in this experimentation work take a series of images for specimens is NIKON (DSLR) D3200.
ii. During the whole experimentation, each of the two light sources was providing as LED sources that were straight illuminating the plate surface.
iii. Data were observed to record the load number and detect the plate response.

The rig was manufactured to combine these above three settings and able to execute the tensile test. It specially manufactured for this work, as shown in the plate shown in Fig 6.

Figure 6. The experimental rig

7.1. Testing layout

The experimental arrangement that used to execute the testing of a 2D DIP application has shown in Fig7.

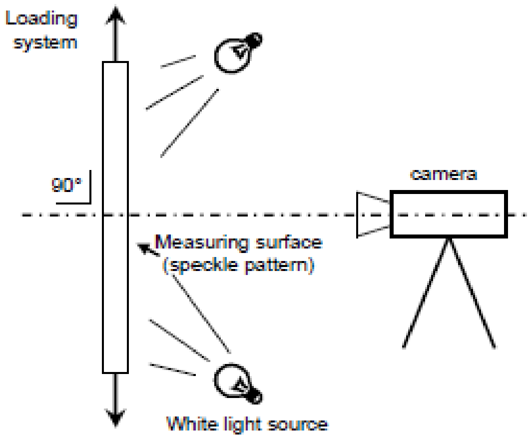


Figure 7. Testing layout used in the current study

Table 1. Plates Dimension

Material	**Plate height (mm)**	**Width (mm)**	**Hole / Notch (mm)**	**Hole / Notch (mm)**	**Thickness (mm)**	Crack and/or Defect Geometry (Length, Width, and Angle) as DIP
Copper	103.24	153.71	30 mm notch	30 mm notch	2.53	
Aluminum	102.17	154.35	20 mm notch	20 mm notch	1.51	

The flat sample used in this test is mounted in a testing rig lighted with two individual white lights. The DSLR camera was positioned on a tripod facing the specimen, which is the main part of the test by taking one first image prior the test and series image throughout the test processes.

The images will be checked firstly, analyzed, and correlated with one after another in order crack/defect detection and geometry measurement. The central optical layout axis has to be in the perpendicular direction of the camera, with respect to plate surface.

The working distance (which defined between the target surface and the support of the cameras) was set about 0.66 mm. Furthermore, another type of aluminium can be used in this experiment [23].

7.2. The Camera

In this research, the experimental work, a single DSLR NIKON D3200 camera employed for taking a series of the images of the samples. The camera resolution is 24.2 megapixels, and the maximum image size is as large as 6016×4000. In the test, the camera is capturing with "Remote Capture". The camera was mounted with a tripod, that gives the capability to adjust the camera in X-Y directions, the angle between the tested surface and the camera, has to be in a zero difference. This can be accomplished via a bubble water level. The camera was positioned 66cm distance from the tested surface. For more information, Table. 2 will review the used optical system parameters.

To concentrate the image on a tested surface, the aperture of the lens needs to be as much open as possible (minimum depth of field). Yet, in the camera, setting the advantage was for shooting speed, which is preferred as 1/25 sec and that also is depending on the light exposure this setting is essential to put in consideration that is to improve the depth of field during the testing. The lighting source was adapted to guarantee an even illumination of the tested surface and to prevent over exposition.

Table 2. Optical system parameters

Camera Type	DSLR
Model	NIKON D3200
Shutter time	Below 1/25 sec
Lens Model	Tamron SP 90mm F/2.8 Di VC USD 1:1 Macro (Model F017)
Lens Type	Telephoto Prime Macro
Focal Length	90mm
Max and Min Aperture for the lens.	f/2.8 & f/32
Magnification Ratio	1.0x / 1:1
Focus Type	Autofocus

7.3. Surface features

Commonly, it is not conceivable to detect the coincidence of matching between each pixel in the reference and deformed image because the grey value which is related for each pixel can be the same value of other thousands of pixels in the next image by no other exclusive correspondence. For this purpose, the examination processes consider the consistency of the slight neighborhood everywhere around the pixel of which named as the region of interest (ROI). The "subsets", the technique can still not simply find the consistency of a designated subset both images. The "aperture problem" [21] it is such an essential to display a surfaced appearance. Meanwhile, the consistency has to be exclusive, i.e., the corresponding progression has to discover a unique, effective corresponding position ("correspondence problem", [21]) Consistent surfaces (e.g., ordinates grids) have so to be avoided. Based on the explanation above, to make the DIC application correct, a randomly surfaced (flat) measurements are mandatory. This texture (usually named "speckle pattern") which can be artificially made on the tested surface before the test is begin as shown in Fig 8 or by applying spray paint of white and then black as 50 percent for white and black.

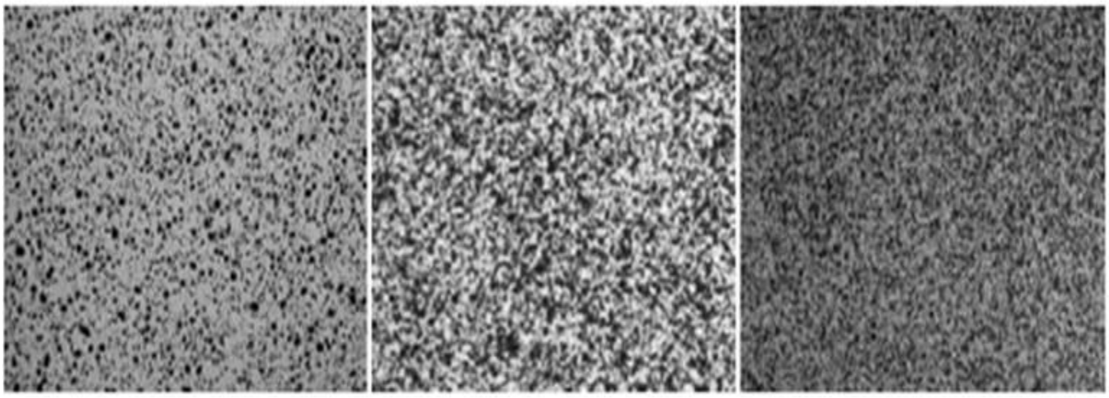


Figure 8. Examples of typical speckle patterns [20]

Spray painting is the method, which generally utilized procedure to make the speckle pattern accomplishment. Several different techniques were developed in the years speckle pattern as particular different scales and the material applications [21]. There are cases in which the natural textures of the tested surfaces of the materials are enough themselves to be applied in DIC. The features of the realized speckle pattern are intensely affecting the quality of DIC results.

7.4. Mechanical loading system

In this test loading system, the tensile load was carried out using a sample equipment assembly to preformed tensile load purposes. It is the manually controlled system that is capable of performing wide ranges of a load as required in present work. It assembled to be able to bear a high load, manufactured from (7mm) C channel beam welded together. The clamping system had been used, the top clamp is a mechanical moving grip, and the lower clamp is a fixed mechanical grip manufactured from a 4 mm plate sheet fixed with screws to make the specimen replacement easy. LPC5000 load cell with digital weight indicator, iron chain to transmission load, and scissors jack have been used to supply the tensile load on the mechanical upper grips and the blade. It can also change the directions of the force so both loading and unloading stages can be achieved.

7.5. Monitoring and measuring instrumentation

Several types of measuring and monitoring instruments have been used in the test part of this work. They used to measure crack length, load value, and the number of load cycles.

The factors that play the main rule in the measurement process:

1- Loading (Test Machine)
- Misalignment
- Vibrations
- Calibration

2- Specimen (Speckle Pattern)
- Size
- Shape
- Contrast
- Illumination

3- Sensor (Camera)
- Resolution
- Dynamic range
- Aperture
- Exposure
- Noise
- Lens Distortions

4- Analysis (Software)
- DIP to measure crack/defect geometry.

7.6. Measuring instrument

The measuring instruments, which were used in this test, are as below:

1. To measure the actual plate dimensions after installation and the geometry of the crack digital Vernier calliper (IP 54) with 0-300 mm rang and 0.01 mm resolution was utilized.
2. Load cell type (LPC5000) which can stand up to 5 Tone with a weight indicator was used to measure the load.

3. LCD screen to read the load extracted from the load cell continuously as shown Fig 6.
4. Two LED flashlights had used from both side of the specimen under tensile to give the desired and equal light distribution.
5. Remote shutter used to take individual shots for the camera to avoid the vibration may cause by camera touching.

7.7. The experimental procedures

The experimental work was executed based on some theoretical considerations such as the location of the maximum tensile load on the tested surface to set the experimental load in the right way. The testing procedure can be summarized in several steps as:

7.8. The experimental steps used for the tensile test

i. Switch on the power from the power source to the LCD load reader.
ii. Set the camera tripod in the horizontal ground level, so that there is no inclination angle, later in the test set-up, the optical system was position to face the surface of the specimen.
iii. Switch on both LED lights and check the light distribution on the plate in the camera screen.
iv. Tight both chains enough, so the start of the loading will be more precise.
v. Make the theoretical calculation to put the upper load limit.
vi. Record the load reading continuously with 100 kg interval.
vii. The same above work was executed in terms of pre-loading, placing the camera, lighting source and the recording parameters.
viii. The tested surface needs to have a notch of 20 mm, 30 mm in the Aluminum alloy Copper alloy plates respectively, due to the plate thickness difference.
ix. The crack/defect is continuously measured with Vernier before starting the load and after each step of load rising, so that the validity of the DIP technique will be checked in advance.

8. Results and discussion

8.1. Crack-Path optimization

The developed program is dependent on a fair guess, on the crack route positioning for the reference conformation. The crack route can be detected by converting the image into a grayscale map. The crack position can be predicted by finding the lowest grayscale value, which indicates the crack initiation highlighted in both Fig 9 and 10.

However, this early guess for the crack path indication might still have eccentricities from the actual crack pathway that may source of miscorrelation. To overcome this problem, a crack-path optimization procedure is performed by increasing the search path and let the code shifts up and down to make sure that the correlation is in the middle of the crack and follow it, even with an angle found.

The crack path search is initially must be defined by nodes with 1-pixel increments. For each image that is correlated, the grayscale values are checked along the crack path to ensure the lowest values on the crack path. In this way, the code will continue on the lowest grey value that indicates the crack path.

Here, the crack results are divided into two fields, the first is related to the DIP that is used to identify the location of any crack/defect on the plate surface, and estimate the related geometry for this crack/defect including angle, width and length. The results found were perfectly matching (97%) the actual measurement of the crack/defect geometry.

The developed program requires the actual width and height of the plate to estimate the crack geometry within true dimensions.

8.2. Copper alloy specimen with inclined crack

The Fig 9 below demonstrate the collected results from the developed program. The results of DIP program had been related with the actual physical dimensions, an agreeable differential between the written program and actual physical measurements had been achieved.

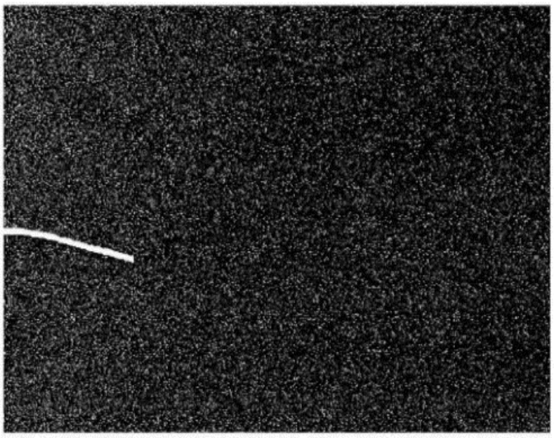


Figure 9. Crack / defect location detection

Figure 10. Crack/defect the area

8.3 Aluminium alloy specimen with horizontal crack

An aluminium specimen with a non-inclined notch represents a big crack is examined by means of the written developed program and related with the actual physical dimensions using calibrated digital vernier calliper (IP 54). The sample is shown in Fig12. The sample is of 154.35 mm, 102.17 mm, 1.51 mm width, height, and thickness respectively. The specimen is loaded by a tensile force of 25000 N in the y-direction. The sample is set to be analyzed by DIP. The developed program computes the crack geometry in terms of width, length and angle measurements and highlight its location. The results that had been extracted from this DIP in an acceptable agreement compared to actual physical measurements as is shown in Fig 11 and 12.

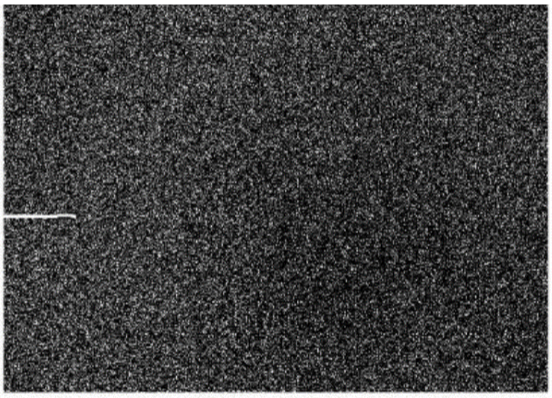


Figure 11. Crack/defect location detection for the second case

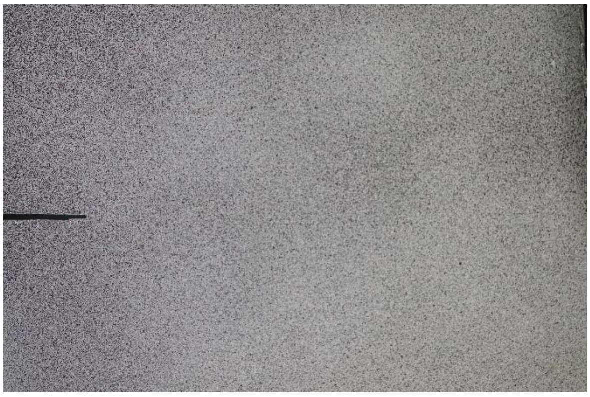


Figure 12. Crack/defect area

9. Conclusions

i. Tensile tests have been carried out for two cracked/defected specimens. The tests applied for both flat Aluminum alloy and Copper alloy plates. The DIP percentage of accuracy differs from (97) % to (99) % by comparing with the actual physical measurements.
ii. The DIP technique can be developed in Structural Research laboratories, and make it possible to perform and work with the fatigue testing and/or crack propagation without human surveillance.
iii. The measuring of crack geometry can be easily used by the developed program, it just needs an operator who is familiar with this kind of testing.
iv. DIP had successfully used in the determination of the actual crack position, and it allows us to measure the actual length, width, and angle of the crack/defect.

v. For quick and reliable surface defect inspection, the DIP program for crack detection is effective technique using instead of the slower traditional human inspection method. Automatic crack detection is very useful for Non-destructive testing (NDT). By manual investigation, it is hard to evaluate deterioration accurately [24]. The automatic crack detection can be implemented using some of the NDT procedures like (i) Radiographic, (ii) Ultrasonic (UT), (iii) Laser, and (iv) Infrared and thermal [24].

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